Vol. 35, No. 1
April 2017

JOURNAL OF
RADIATION
EFFECTS

Research and Engineering

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This paper was presented at the 33rd Annual HEART Technical Interchange Meeting
Monterey, CA, April 5 – 8, 2016.

Prepared by AECOM for the HEART Society under contract to NSWC Crane.

This work was sponsored by the Defense Threat Reduction Agency under MIPR # HDTRA1517421.

JOURNAL OF RADIATION EFFECTS,
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A SPATIAL AND TEMPORAL CHARACTERIZATION OF THE BACKGROUND NEUTRON ENVIRONMENT AT THE NAVY AND MARINE CORPS MEMORIAL STADIUM

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Abstract

This project utilized neutron detection near the Naval Academy football stadium in order to map and quantify the effect of the stadium structure (primarily steel reinforced concrete) on the background neutron environment. The venue exhibited varying levels of neutron background radiation. The temporal variation of background was also observed over the period of two months. The results of this project are useful in planning, conducting, and assessing the utility and limitations of radiation surveys using current state-of-the-art portable or stationary detection equipment at venues.

Introduction

The Navy and Marine Corps Memorial Stadium is the U.S. Naval Academy's football venue in Annapolis, Maryland, with a seating capacity of 34,000. In a security environment, where large public venues may be a target for terrorist activity, the ability to survey venues for radiological or nuclear materials out of regulatory control may be of interest. Around a structure such as a stadium, the large quantity of steel and concrete may have an impact on background radiation through a phenomenon known as the ship effect [1]. The neutron ship effect is a phenomenon involving high energy cosmic radiation that interacts preferentially with high atomic number materials to produce additional background radiation. Though the gamma background is primarily caused by naturally occurring radioactive material, the neutron background is primarily caused by cosmic particle interactions, so the over ground ship effect is expected to be most noticeable for neutrons. This ship effect's impact on radiation background must be understood in order to develop effective survey protocols around venues.

Background

Spatial changes in neutron background have previously been characterized around a ship by Rydalch [2], where neutron background was shown to increase by over 40% on approaching a vessel. Recent work at Oak Ridge National Laboratory has shown that the local radiation environment can be a function of altitude, moon phase, and tide [3], [4]. Pacific Northwest National Laboratory has quantified the change in neutron background seen in a portal monitor with the passage of large quantities of high atomic number cargo [5]. Ziegler and Puchner have provided a characterization of background neutrons at sea level in both flux and energy, indicating three distinct groups: very high energy neutrons (10 – 1000 MeV) resulting directly from cosmic particle cascades, high energy neutrons (0.1 – 5 MeV) resulting from spallation or n,2n reactions, and thermal neutrons [6]. Note that the second group is caused by the same phenomenon as the ship effect, and that moderated thermal neutron detectors will respond to all three groups and will not be able to distinguish between them. Dirk *et al.* [7] have shown variations of neutron background across a broad range of measurement locations, including a determination of the shielding effect of concrete by measuring the thermal neutron background inside a concrete building at various levels in the building, showing a reduction to 20% the incident value after a concrete thickness of 5 feet. This same study showed variations in thermal neutron background with elevation and spatially over a 100 mile diameter area surrounding a large city. This current work is complementary to previous research by providing a detailed neutron background characterization of a venue of interest, on which a tailored and durable survey protocol may be based for both mobile and stationary sensors. A generalization of venues may be difficult, so similar characterizations may be warranted in other locations of interest.

This project utilized a neutron detector for data collection: the USNA's ^{3}He based Large Neutron Sensor (LNS) to

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measure the background neutron radiation surrounding the stadium to develop a spatial and temporal radiological characterization of the site. Additionally, stationary data were collected over a 53-day period less than one mile from the stadium to characterize the temporal variation of the neutron background. This work demonstrated wide variation, both spatially and temporally, of the neutron background, highlighting the importance of developing informed survey protocols.

Experimental Method

The neutron detector used in this research was the Large Neutron Sensor (LNS), containing four large and independent ^{3}He tubes, each approximately 6 inches in diameter and 6 feet long and with a fill pressure of slightly more than one atmosphere [8]. This sensor is packaged in an environmental closure that includes a high voltage power supply, signal processing capability, and a four channel data recorder. There are two external connections to the LNS: 24 Volts (line in) and a USB data connection to the data recorder. The ^{3}He tubes are surrounded by polyethylene and polyethylene foam to provide moderation. The entire detector weighs approximately 300 pounds and is mounted on a wheeled cart to allow mobility. The detector and cart are pictured in Fig. 1.

Additional equipment used included a mobile 24V power source, a laptop computer for data recording, and a GPS receiver and laser distance measurer for determination of position and relative position.

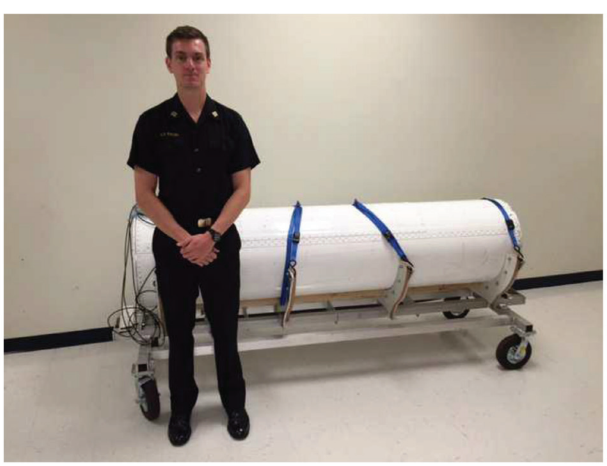

Figure 1. USNA's large neutron sensor.

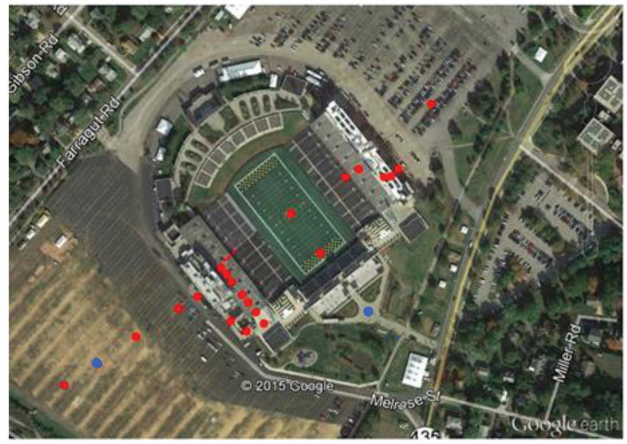

Figure 2. Spatial survey locations.

Spatial data were collected in six survey activities from September 24, 2015, to November 19, 2015, comprising 39 data points, each from a 10-minute count. Each survey activity was conducted over a two to three hour period and included a 10-minute measurement at a common baseline location to be used in day-to-day data normalization (blue points in Fig. 2). This normalization was necessary because of large variations seen in the daily baseline measurements and all normalization was done using the daily baseline and the lowest observed baseline measurement. While the absolute efficiency of the LNS has not been determined, it is very high compared to other neutron detectors with a typical background response of around 15 counts per second, providing a statistical error of around 1% in a 600 second count.

Temporal data were collected at the stadium as non-continuous (day-to-day) values through the daily baseline measurements (each of six collection days). Continuous temporal data were collected from one location, at a USNA academic building approximately one mile from the stadium, from January 30, 2016, to March 21, 2016, comprising 53 days of continuous temporal data.

Fig. 2 shows all 10-minute survey locations, indicated by red and blue points, where neutron data were collected. Data were collected multiple times at some of the points. Data were collected at the blue points on each survey day to allow data normalization. For the data collected at points indicated on Fig. 2 but not specifically addressed in this paper, the trends were similar to those reported. For all locations with full overhead exposure, the counts were similar to the baseline counts.

Results of Spatial Measurements

The first spatial trend explored was an approach to the stadium. The anticipated result based on the ship effect was an increase in neutron counts as the detector came closer to the stadium. An overhead map and the resulting data are both shown in Fig. 3 and Fig. 4. Note, in Fig. 4, that the data outside 100 feet from the stadium structure are all within 1 standard deviation of each other, so data across the parking lot on the approach may be considered constant.

The data taken at a point 6 feet from the base of the stadium tower (green mark in Fig. 3), shown as the left most point in Fig. 4, was 7 standard deviations below the mean parking lot value. The probable cause of this decrease in count is shielding effect, rather than the anticipated ship effect increase.

Considering this observed shielding effect, rather than a ship effect, together with the similar compositions of Earth and concrete [9] as seen in Fig. 5, it follows that without extensive steel reinforcement, concrete may yield the same effect on neutron background as Earth, so the ship effect may not be observed around concrete structures.

The second spatial trend considered was entry into the main stadium concourse. Note that all but the two blue points indicated in Fig. 6 are obscured from overhead view by stadium seating and structure, and that movement toward the middle of the concourse is away from the opening.

The results of this survey are indicated in Fig. 7 (see next page), where a clear and consistent decrease is seen upon entry into the concourse area. Note that the final reading, taken at the midpoint of the concourse (i.e., 180 feet under the concourse), showed a reduction of 45% in neutron background compared to the background reading taken 25 feet from the overhead seating area. Also based on anticipated Poisson counting statistics, the error bars associated with these data points would represent less than 2% of each value, and would in all cases be contained within the data marker.

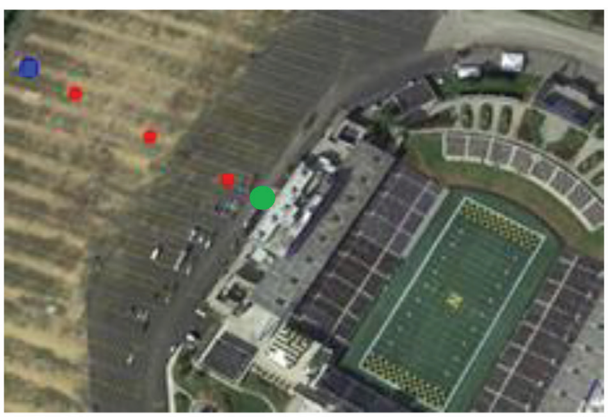

Figure 3. Data collection points for stadium approach.

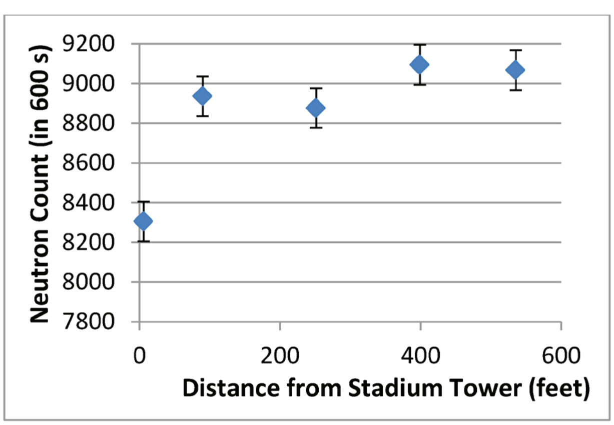

Figure 4. Neutron background on stadium approach.

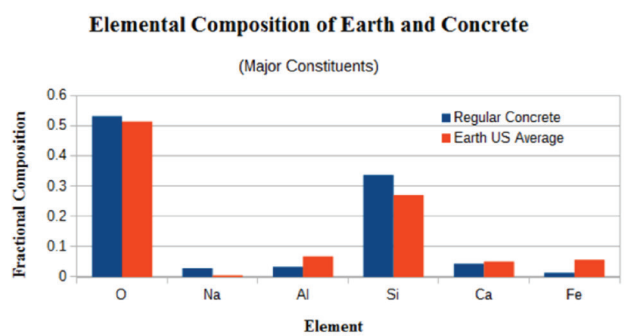

Figure 5. Elemental composition of concrete and earth.

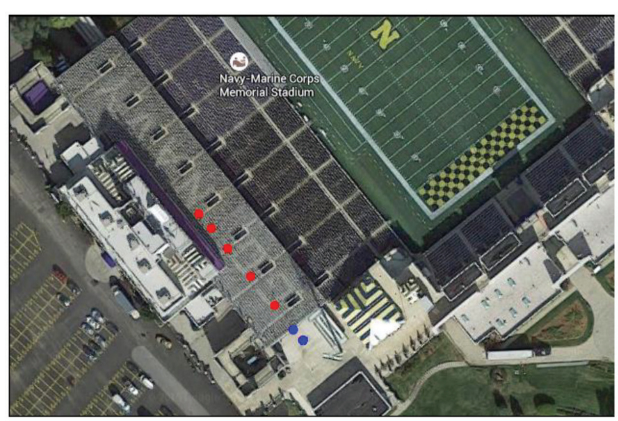

Figure 6. Data collection points for concourse entry.

A third spatial trend considered was movement from the exposed seating area, through a tunnel ramp to a location close to the midpoint of the concourse.

Fig. 8 and Fig. 9 show the data collection in the tunnel and the results. In this case the neutron count rate was observed to drop by 37% in a distance of 45 feet through the tunnel. The notable feature of this survey is the short distance over which the neutron background is observed to significantly change, likely due to the large amount of concrete surrounding and confining the ramp, limiting neutron exposure.

Results of Temporal Measurements

For a period of 53 days, from January 30, 2016, to March 21, 2016, the LNS was continuously operating on the ground floor of a USNA academic building, adjacent to an exterior roll-up door. Data were continuously recorded, with counts placed in 10-minute bins. The results of this survey are indicated in Fig. 10.

Note that Fig. 10 shows the combined result from the four independent tubes, though the same trends were also observed in the response of each tube individually. Individual and combined metrics are shown in Table 1 (see next page), where STD represents the standard deviation and the range shown is the difference between the maximum and minimum counts recorded in a 10-minute period.

There are several interesting conclusions that can be drawn from the trends seen in Fig. 10, including the facts

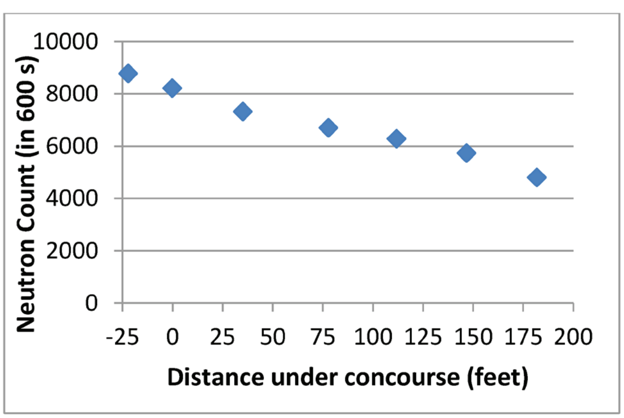

Figure 7. Neutron background on concourse entry showing a 45% reduction in 180 feet.

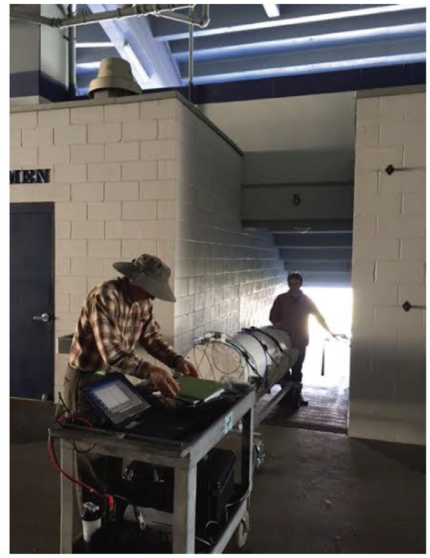

Figure 8. Data collection in tunnel from seating to concourse.

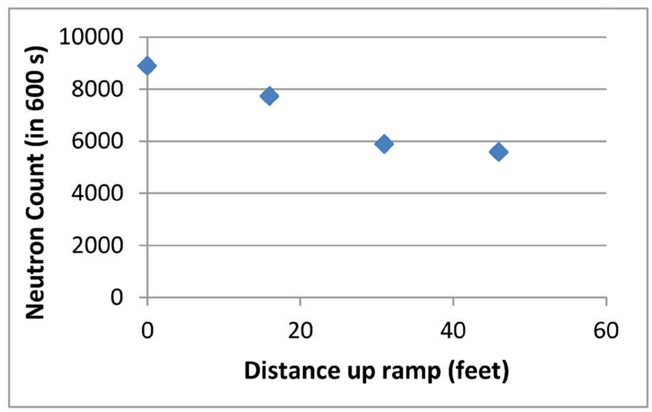

Figure 9. Neutron background in seating - concourse tunnel ramp, showing a 37% reduction in 45 feet.

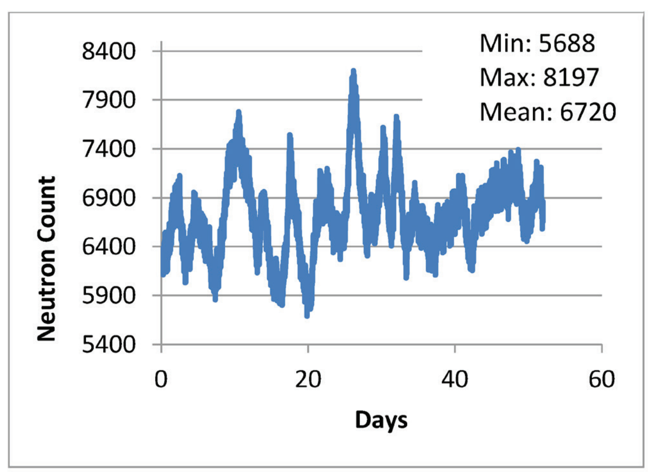

Figure 10. Temporal nature of neutron background: 53 days.

that a diurnal cycle is not obvious, and trends are consistent over periods of several days. An analysis of the most dramatic positive increases shows rise times of more than one day and a change rate of 2% per hour.

Table 1. Temporal neutron background data for 10-minute counts for each of the 4 tubes in LNS for a 53-day period.

	Mean	STD	Max	Min	Range
Tube 1	1575.6	98.0	1994	1272	722
Tube 2	1643.7	106.4	2053	1321	732
Tube 3	1772.0	107.3	2182	1459	723
Tube 4	1728.9	103.6	2135	1428	707
LNS total	6720.2	388.9	8197	5688	2509

Conclusions

Rather than a ship effect, a shielding effect was found to be the dominant feature of spatial trends around the stadium. A reduction in neutron background under the stadium structure of up to 45% was seen, with significant changes occurring across distances of 45 feet or less.

Temporal data show multi-day consistent trends, with a range of nearly 40% of the mean value.

An implication of the spatial variation is that dynamic surveys may be less effective than static surveys unless the varying background is accounted for in the survey protocol. For example, in this changing background environment, optimum performance of a mobile survey system will require the alarm threshold for identification of illicit material to change depending on the location in the stadium.

An implication related to the temporal variations seen is that for a stationary survey, a background needs to be reestablished if surveys are to be conducted over periods longer than several hours. Changes in background may be as high as 16% over an eight-hour period.

The temporal trends for the neutron background indicate that weather may be the driving force. There is potential for future research to more fully characterize the temporal nature of the neutron background and develop a model of the varying background based on environmental factors such as air pressure and humidity.

Acknowledgment

The authors express their appreciation to the Defense Threat Reduction Agency, Nuclear Science and Engineering Center (DTRA/NSERC) for their support of this research.

References

[1] G.W. Philips *et al.*, "A Primer on the Detection of Nuclear and Radiological Weapons," National Defense University, Center for Technology and National Security Policy, Washington, DC, 2005.

[2] F.D. Rydalch *et al.*, "Measurement and Modeling of the Neutron Ship Effect Near the USS Barry," *J. of Radiation Effects, Research and Engineering*, vol. 34, no. 1, pp. 197-202, Dec. 2016.

[3] J.E. Gunning *et al.*, "Neutron Background Variation with Altitude," in American Nuclear Society 2013 Winter Meeting, 2013.

[4] J.E. Gunning and A.L. Enders, "The Effect of the Phase of the Moon on Variations in Background Radiation - An Interesting Occurrence," in American Nuclear Society 2012 Winter Meeting, 2012.

[5] R.T. Kouzes *et al.*, "Cosmic-ray-induced ship-effect neutron measurements and implications for cargo scanning at borders," *Nucl. Instruments & Methods in Physics Research, Section A*, vol. 587, pp. 89-100, 2008.

[6] J.F. Ziegler and H. Puchner, *SER - History, Trends and Challenges A Guide for Designing with Memory ICs*, San Jose: Cypress, 2004.

[7] J.D. Dirk *et al.*, "Terrestrial Thermal Neutrons," *IEEE Trans. Nucl. Sci.*, vol. 50, no. 6, pp. 2060-2064, 2003.

[8] R. Kouzes, "SPAWAR Neutron Detector Information, PNWD-4429," Pacific Northwest National Laboratory, Richland, WA, 2014.

[9] R. McConn *et al.*, "Compendium of Material Composition Data for Radiation Transport Modeling," Pacific Northwest National Laboratory, Richland, WA, 2011.